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United States
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Forest Service

Forest Pest
Management

Davis, CA

The USDA Forest Service Pesticide Environmental Fate and Application Development Program - An Overview

FPM 95-10
March 1995

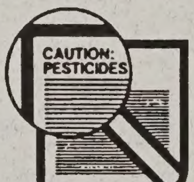
Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.



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The USDA Forest Service Pesticide Environmental Fate and Application Development Program - An Overview

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The USDA Forest Service Pesticide Environmental Fate and Application Development Program - An Overview[1]

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ABSTRACT: The USDA Forest Service, even though a minor user of pesticides, has maintained an active program to understand the performance, atomization, evaporation, efficacy, environmental fate, atmospheric dispersion, and environmental impact of chemical and biological insecticides. Since its self-imposed ban on use of DDT in 1964, the Forest Service has pursued insecticides that have low potential for impact on non-target organisms, application technology that supports their efficient and efficacious use, and computer models that predict their fate in the environment. This program has been active over the last two decades beginning with research for chemical insecticide substitutes for DDT, progressing in time to biological insecticides. In our effort to make the less persistent, and usually less toxic substitutes work, we had to investigate insecticide monitoring, detection, and sampling methods; application systems; atmospheric influences; tank mixes and adjuvants; nozzles and atomization; evaporation; spray deposition and canopy penetration; biological response; and environmental fate. This paper reviews some of this work, with mention of technology that might be applicable to insect vector control.

KEYWORDS: forest spraying,application technology,environmental fate,spray models

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INTRODUCTION

This paper reviews aerial application technology activities supported by the USDA Forest Service pesticide program over the past 25 years. Publications and reports resulting from these activities are listed by Skyler and Barry (1991) with current updates. Others, including the USDA Agricultural Research Service, the Department of Defense, and especially our colleagues in Canada have made significant contributions to our understanding principles and practices of forest spray application technology. Requests for their publications should be sent directly to USDA-ARS (409)260-9364, US Army (801)831-3371, or Canada Forest Service (705)949-9461. New Zealand Forest Research Institute at Rotorua is conducting application research to support aerial application of herbicides in forestry. Their library can be accessed by calling (647)347-5899.

EARLY USE OF AIRCRAFT IN FORESTRY

As reviewed by Barry (1993), "The idea of using aircraft was first announced in 1911 when Alfred Zimmermann, a German forester, was granted a patent by the Imperial Patent Office, Berlin, Germany (Quantick, 1985). The patent was for a technique to use aircraft to apply a pesticide to control forest insect pests, specifically the nun moth (Lymantria monacha L.). Others as early as 1913 suggested the use of aircraft to disperse pesticides (Johansen, 1913; Balch et al., 1955-1956)."

"The first actual use of aircraft to apply pesticides was demonstrated in August 1921 by the State Experiment Station of Ohio (USA) in cooperation with the United States (Military) Air Service. The successful test, conducted at Troy, Ohio, consisted of applying lead arsenate dust from a military Curtis JN6 biplane to a grove of catalpa trees to control catalpa sphinz moth (Ceratomia catalpae (Bdv.)) (Neillie and Houser, 1922). The test was a success; thus demonstrating that theory and practice were realistic."

"From 1936 to 1938 autogiro aircraft were used to study application and deposition of lead arsenate concentrate in woodland (Potts, 1958). This first use of a rotor-wing aircraft to apply a pesticide to trees was followed in the late 1940s by helicopter trials in Yosemite National Park, USA, to control lodge pole needle miner (Coleotechnites milleri (Busck)) with the insecticides DDT and malathion. Results of aerial application became more promising with improvements in chemicals, techniques, and helicopters (Eaton, 1946). Using helicopters to apply DDT for control of a range of insect pests, including cankerworm, gypsy moth and pine bark aphid, Craighead and Brown (1946) noted several advantages over those of the fixed wing airplane; however, the small pay load (95 liters) of the early models was a

distinct disadvantage to forest spraying." (Quoted from Barry, 1993)

By the 1960's the aircraft was well established in North America as a method of applying insecticides to control forest defoliators, especially the gypsy moth, spruce budworm, and tussock moth.

RESEARCH DURING WORLD WAR II

In 1940 the U.S. Office of Research and Development (1946), National Defense Research Committee was established by the president to conduct research on a broad range of science and engineering problems. Scope of this research included:

<u>Micrometeorology and the Behavior of Gas Clouds</u>

- General Meteorological Principles
- Behavior of Gas Clouds
- Field Sampling Methods for Nonpersistent Gases

<u>Aerosols</u>

- General Properties of Aerosols
- Stability of Aerosols and Behavior of Aerosol Particles
- Formation of Aerosols
- Optical Properties of Aerosols
- Measurement of Particle Size and Size Distribution
- Travel and Persistence of Aerosol Clouds

<u>Dispersal Systems</u>

- Atomization of Liquids
- Dispersal of Liquid Droplets
- Dispersion of Herbicides

<u>Other</u>

- Insect Control--The Development of Equipment for the Dispersal of DDT
- Wind-Tunnel Studies of Fog Dispersal, Gas Diffusion, and Flow over Mountainous Terrain

In review of these subjects there was an apparent concern and need for information on factors that influence application technology. Chapter 38 on insect control by Scoville (1946) discusses insect mortality as a function of drop size and penetration of sprays into forest canopies and Rouse's Chapter 43 (Rouse, 1946) discusses wind-tunnel studies of fog dispersal, gas diffusion, and flows over urban and forest settings. The point I want to make regarding World War II research and other early

research that followed, is that many of the same questions we have today were identified by scientists and engineers more than 50 years ago. They did solve some and provided a legacy of information that you will find of interest and helpful.

For those with an interest in reviewing a sample of other papers reporting on earlier application technology work that relates to insect vector control, I have listed a few in the reference section as follows: Potts (1946) - particle size of insecticides, application, distribution, and deposit; Latta et al. (1947) - effect of particle size and velocity on aerosols in wind tunnel on mosquito mortality; LaMer and Hochberg (1948) - deposition and effectiveness of insecticidal aerosols; Himel (1969) optimum size for insecticide spray deposits; Stains et al. (1969) cage mosquito kill up to two miles, low volume generator; Murray and Vaughn (1970) measuring pesticide drift to distances of four miles; Cramer and Boyle (1976) micrometeorology and physics of spray particle behavior; Spillman (1976) probability of drop contact and kill of flying insects, drops 10-30 micrometers; and Yates (1988) prediction of spray deposit patterns and dispersion characteristics from aerial application of BtI using FSCBG model.

A MULTIDISCIPLINARY APPROACH

A partnership between the USDA Forest Service Missoula Technology Development Center and the Forest Pest Management staff has focused on application of pesticides and related technology since the late 1960's. In 1970 this partnership was extended to include the US Army Dugway Proving Ground. Work within this consortium has included the basic science and engineering of pesticide application, atomization, pesticide sampling and monitoring, and assay to understand pesticide behavior in the atmosphere - its drift, deposition, impaction, volatilization, and penetration into canopies. The ultimate goal, while not apparent in 1970, was to capture and organize all that was known, as well as any new information on this subject and develop a system that could organize and deliver information in a practical manner for use by the field practitioner, researcher, and regulator. The system would assist the field practitioner in developing aerial spray prescriptions for safe, efficacious, and economical applications; would serve the researchers in studying application problems such as sensitivity of one or more factors on drift environmental fate and efficacy as examples; would serve operators as a platform for extending decision support systems and for planning and dose response predictors; and serve the regulator in establishing pesticide use guidelines and restrictions.

Our business is one of the most interdisciplinary of the applied sciences and engineering. Those involved in pesticide application technology over the past 50-60 years were ahead of

their time in recognizing the need for a multidisciplinary approach. There is no one professional society for publication of our papers; although we are more closely associated with the American Society of Agricultural Engineers. Our papers are published in a variety of journals. Perhaps other applied disciplines have experienced a similar situation. A case at point is the discipline of archaeology. Little had changed in their field methods since Thomas Jefferson developed the stratum approach to excavation of burial mounds on his Virginia property. For the next century and a half little changed, objects like axe heads, readily identified as prehistoric tools, were dug and labeled by the strata or layer from which they were dug. Stone items were obvious but these alone provided minimal information on the culture. Scientists who might have contributed other interpretation to early cultural material through other artifacts associated with mounds were not involved. The discovered was repeatedly rediscovered. Today the field teams, in addition to archaeologists, might include biologists, microbiologists, chemists, physicists, engineers, medical doctors, sociologists, and their sub-disciplines. Human hair follicles analyzed for DNA might yield more important information on an event than all the axe heads collected over the past 200 years. With the integration of other disciplines we are beginning to unravel the mysteries of "peopling" the New World.

So it is with the multidiscipline of pesticide applications Figure 1 (modified after M.A. Matthews, 1979) helps to position our discipline within the broad world of science and engineering. You will note that the primary disciplines and many of the sub-disciplines are represented specifically or by the functions they serve. And several are represented in this audience I am addressing this morning.

Now that we have added the knowledge of numerous disciplines to an already full platter, how do we integrate, position, organize and call upon this massive knowledge base to address user needs? Our training and experience suggests a file system for organization, an analytical system for integration and analyses, and an output system with answers we can understand, explain, and apply. Of course what I am talking about are simulation models, expert systems, and decision support systems, taking note that each of the three can be quite different.

The modern era of simulation modeling began with the main frame computer. The advent of the personal computer in the 1970's ushered forth opportunities for most everyone to perform simulation modeling.

Simulation models are important for one simple reason - if we can predict an event with repeatability we are at the point of mastering an understanding of the agents and their relationships that join to cause the event. Such mastery provides a powerful

and credible tool that can provide answers to support pesticide development, registration, and use.

Much of the information to be presented this morning will speak to the FSCBG aerial spray simulation model (Teske, et al., 1993) that was developed jointly by the USDA Forest Service and the US Army. The initial development of FSCBG was performed by H. E. Cramer (Cramer and Boyle, 1976) and R. Keith Dumbauld assisted by their colleagues at the H. E. Cramer Co., Salt Lake City under contract to the US Army and USDA Forest Service. Keith and Harry E. Cramer (Dumbauld and Cramer, 1978) reviewed their modeling work in a compendium document on the Douglas-fir tussock moth published by the US Department of Agriculture (Brooks et al., 1978). Most of the other Dumbauld and Cramer papers are listed in the bibliography authored by Skyler and Barry (1993).

The first use of a Gaussian plume model in forestry occurred in 1970. The H. E. Cramer Co. and US Army used an early version of a model (Cramer, et al., 1972) that later would become FSCBG to calculate the dispersion of an insecticide cloud. The test was conducted on the Nez Perce National Forest near White Bird, Idaho in 1971, (Dumbauld et al., 1975; Waldron, 1975; and Barry et al., 1974).

SPRAY SYSTEMS

In response to interest in small drop technology generated by researchers at the USDA Forest Service, Pacific Forest and Range Experiment Station in the 1960's, the Forest Service developed a pressurized spray system for the DC-3 Dakota aircraft (Jasumback and Mattila, 1970). In the early 1970's the Forest Service cooperated with the US Army (Desert Test Center, Ft. Douglas, UT) to test a portable spray system (PWU-5/A USAF Modular Internal Spray System) developed by the US Air Force for C-46, C-47, and C-130 aircraft. After an attempted field test in the Lolo National Forest in 1972 using a C-47 to spray Zectran, the engineering testing was terminated due to project cancellation by the US Air Force (Taylor et al., 1972). A version of the fire retardant modular system is being used by the Air National Guard in California.

Currently the Forest Service is not developing or testing new aerial spray systems. Generally existing commercial systems and atomization devices meet Forest Service needs (Barry, 1993). We do, however, find that performance information is needed for new tank mixes. We, therefore, might find it necessary to conduct wind tunnel or field tests and/or FSCBG model runs.

Aerial application of some biorational agents, eg pheromones, may present challenges when using existing or new spray devices designed for their application (Hall and Barry, 1995). The

Forest Service does not anticipate pheromone applicator development work in the near future.

SPRAY AIRCRAFT

Potential aircraft for forest spraying are well described in a Forest Service publication prepared by Hardy (1987). This publication profiles, with scale drawings, nearly every aircraft that has been used or has the potential of being used for aerial spraying from small helicopters to the multi-engine C-130H and DC-7 aircraft, to apply pesticides. The book has been distributed world-wide and the technical data from this publication has been entered into the FSCBG database. The aircraft wake/vortex descriptors in FSCBG differ for each type of aircraft; thus this database is both essential and a great convenience to the FSCBG user. The Forest Service has no aircraft of its own configured for spraying. We rely on contractor aircraft and occasionally upon the USAF's (LTC Terry Biery) C-130H for testing and cooperative control operations on DOD lands (Barry and Ekblad, 1989 and 1983, and Rafferty et al., 1989).

What aircraft is most suited to forest spraying? The answer of course connects to the job to be done. The Forest Service has a computer model CASPR (Computer Assisted Spray Productivity Routine), developed after the Baltin-Amsden formula (Amsden, 1960) that predicts the cost of an aircraft to treat a block using inputs such as load capacity, turn-times, speed, and several other inputs. CASPR is suggested for helping managers/operators in selecting the most suitable aircraft for a specific job among those that might be available. Generally we prefer small helicopters (eg Hiller 12E Soloy or Bell 206 Jet Ranger class) for small blocks and larger helicopters and fixed-wing aircraft for larger blocks. The main criteria is capability to fly close to the canopy to minimize drift and to maximize penetration into the canopy. Safety is the overriding consideration.

Lane separation (swath width) for various combinations of aircraft type, tank mixes, and spray systems are often debated. Applicators sometimes favor a wider lane separation than our experience and FSCBG will support. The question is often settled by conducting an aircraft field characterization test where the aircraft sprays over a line of cards following procedures recommended by Dumbauld and Rafferty (1977). With FSCBG these costly flybys are not technically necessary unless the aircraft and atomization information are not available for input to FSCBG.

EQUIPMENT CALIBRATION

One of the shocks experienced when I first become acquainted with Forest Service aerial spray operations was lack of a quality control program with our aerial contractors. Not only were aircraft spraying the forests in a highly variable swath spacing pattern (Barry, 1977 and Teske et al., 1994) and excessively high release heights, in many cases they were not even calibrated to apply the proper amount of spray. Tony Jasumback, MTDC, was one of the first Forest Service engineers to work on this problem by providing on-site engineering and equipment calibration consultations in the late 1960's. The problem became more acute when the insecticide DDT was voluntarily banned by the Forest Service and less persistent insecticides that required more attention to proper application were substituted. Failure of these substitutes was attributed primarily to poor application and calibration. There was no room for error when using the low persistent substitutes. Beginning in 1976 the Forest Service began training personnel on aircraft calibration and initiated broad scale calibration checks on most contractor aircraft. Seldom did I observe an aircraft that was noted to be "ready to go and calibrated" to be actually calibrated. Application quality, however, has steadily improved since the late 1970's with applicators, pesticide technical representatives, and Forest Service technicians working together to improve quality of aerial application. Better trained personnel, positive attitudes, concern for costs, demands for improved efficacy, a proactive effort on part of Forest Service entomologists, new technology, and personnel training have led to significant improvements in application quality. But we continue our vigilance.

WIND TUNNEL ATOMIZATION STUDIES

The USDA Forest Service was the primary sponsor of studies at the University of California, Department of Agricultural and Biological Engineering, Davis, CA, to characterize the droplet spectrum of spray from nozzles and atomizers of interest to the Forest Service. Knowing the number and size of drops being atomized is the single most important input to the FSCBG model. Calculations begin with the atomization which is essential to accurate prediction of drift, deposition, and accountancy. The studies were conducted in a wind tunnel where wind velocity, atomization, spray device position, and other factors could be controlled and measured. The Particle Measuring System (PMS) was used to measure individual particles as described by Yates et al., 1982a, 1982b, and 1983). Result of the Forest Service sponsored atomization studies were reported in a compendium by Skyler and Barry (1991) and is part of the FSCBG database. Developing a capability to characterize the atomization of spray nozzles and atomizers was a major breakthrough. Before this capability we could only estimate atomization by using methods subject to considerable error. Since the initial sponsorship by

the Forest Service that demonstrated the feasibility of this approach, others in academia and private sector have constructed wind tunnels to characterize formulations, spray devices and tank mixes. Nozzle characterization services are now available for hire in the private sector.

FORMULATIONS AND TANK MIXES

The Forest Service applies insecticides both in ultra low and low volume sprays using rotary atomizers like the Beecomist and Micronair. For ultra low volume we apply tank mixes undiluted at or below 1 gallon per acre. Bacillus thuringiensis is the primary insecticide applied by aircraft with minor applications of Dimilin through its cooperation with the States. Gypsy moth virus and Douglas-fir tussock moth virus (Hofacker el al., 1980) have been applied as low volume at 1-2 gallons per acre. Ultra low volume and low volume sprays offer several advantages over the diluted and higher volume tank mixes. Costs are reduced through no mixing and larger payloads in terms of treatment area and travel time. Efficacy is increased on a volume to volume basis over diluted sprays because the active ingredient is concentrated in drops (mostly small drops below 100 micrometers) that reach the intended biological target with adequate toxin to cause mortality. Ultra low volume also reduces tank mix volatilization problems and eliminates need for adjuvants as the formulation contains all necessary additives. Effectiveness of Forest Service application programs has been significantly increased with improved formulation and ultra low volume application. Joyce (1975), Himel (1967), and others are credited with the research that encouraged ultra low volume spraying.

SPRAY VOLATILIZATION

Evaporation of volatiles from tank mixes after they have been released from the nozzles has been a major concern to all who have been involved in aerial application. We have investigated this problem for several years in an attempt to understand, predict, and manage evaporation. Both the diluent carrier (usually water) and the diluent in the formulation (concentrate that's produced by the manufacturer) are subject to evaporation. The active ingredient generally is not. This becomes paramount in accounting for the fate of material in the atmosphere - if the material has volatilized, one has no basis to argue that the mass lost to evaporation equates to loss or unaccountability of active ingredient. When fate of the active ingredient in the environment is of interest one should select samplers that are efficient for the range of drop sizes that contain the active ingredient. This is a challenge given that drops are falling out as the cloud transverses downwind while evaporating at the same time. Volatilization can be predicted and is a capability of FSCBG.

The FSCBG model accounts for evaporation in computing drift and total accountancy of spray (Teske et al., 1994). Recent unpublished information (Temple Bowen and Chris Riley discussions) strongly argues that most sprays from most tank mixes evaporate at a rate similar to water - that is until its water content is lost. Smaller amounts of non-water volatiles will evaporate according to their physical and chemical properties. FSCBG has the capability of handling evaporation of all types of pesticide tank mixes.

SPRAY DRIFT

Drift has become defined as movement of spray off target. Realistically we cannot entirely prevent either the movement or drift of spray but we can manage it with existing knowledge and technology to the point that it is not significant.

Drift and environmental fate of spray from aerial release of pesticides has been one of the primary focus areas for agricultural spray researchers over the past 25 years (as examples - Ware et al., 1969, 1970, 1972a, and 1972b). Drift has become even more important with increased concerns of pesticides in the environment and more aggressive regulatory actions. The new US Environmental Protection Agency (EPA) pesticide labeling requires that drift mitigation information be specified on pesticides labels. This has brought to the forefront information and technology that the USDA and others have developed on drift management. The Forest Service program while producing information on drift in forest operations (Barry et al., 1987, and 1993, Barry, 1984a and 1985; Barry and Ekblad, 1983; and Markin, 1982) has emphasized how to maximize deposition on the target thus reducing waste of pesticide that might drift or otherwise be lost beyond the target. Cramer and Boyle (1976), Ekblad (1977), and Ekblad and Barry (1984) reviewed the influence of meteorology on pesticide application and drift noting the complex relationship among numerous physical and atmospheric processes. The processes would eventually be addressed by the FSCBG model. The Spray Drift Task Force (SDTF), a consortium of agricultural chemical manufacturers, will be providing EPA drift management information in the near future. The SDTF has further substantiated with field data those conditions that should be avoided or favored in managing spray drift. We look forward to the release of their scientific findings.

As all of us know and have experienced, drift is a tracer of atmospheric conditions, primarily horizontal and vertical air movements and temperatures. In ultra low volume and low volume spraying we are dependent upon wind to move the spray within treatment areas to help disperse the insecticide. Some uses of insecticides to control insect vectors over large areas depend upon wind to carry (drift) and mix the material. Wind is also used as an ally in moving the spray away from sensitive areas.

With the FSCBG model coupled to knowledge and understanding of aerial application we have the capability to develop spray prescriptions that will deliver most of the spray to the target, safely and efficaciously, while minimizing off target drift and environmental impact. The challenge is demonstrating and applying this technology. The knowledge and tools are there to do the job.

WEATHER MONITORING

In our experimental and field programs since 1970 we have used a variety of weather measuring instruments and towers. Harold Thistle at the Missoula Technology and Equipment Development Center is the Forest Service professional on atmospheric science, meteorological data acquisition, and other application technologies. Realizing the critical necessity of understanding the atmospheric environment of target areas, we usually plan for instrumentation to monitor the weather. In doing so we have experienced both successes and failures. Bob Ekblad who worked on spray weather studies and instrumentation needs for much of his Forest Service career, tested and demonstrated the utility of the EMCOT (Event Model for Complex Terrain) weather station for surface observation to support Forest Service field projects (Ekblad et al., 1990). The instrument is designed to accept any sensor that emits an analog or pulse of electrical output signal, eg wind speed, temperature, and relative humidity. It has a mast that extends to 20.5 feet; although higher masts are available. The station has proven its utility on both experimental and operational projects.

SPRAY SAMPLING TECHNOLOGY

An ability to sample the deposition and air concentration of insecticide sprays is essential to improving application technology, conducting sound field tests, conducting safe operational projects, understanding the behavior and fate of sprays in the atmosphere and target area, and addressing environmental concerns. In experimental work the Forest Service uses various types of samplers for quantitative, and in some cases qualitative, assessment of spray deposit on target and off target.

Most sampling technology used by the Forest Service has been adapted from that used by the former USDA Bureau of Entomology and Plant Quaranteen where Davis and Elliot (1953) used deposit cards to sample deposit of oil sprays; and from the US Army and US Public Health Service scientists and engineers who developed numerous devices to sample chemical and biological materials including gases, aerosols, and particulates in the atmosphere. Some of the samplers were designed to provide time concentrations and dosages (dose/time) data. The samplers are described by Wolf et al. (1959) and to this day the publication remains one of the

best references on samplers and support equipment. The Forest Service references for spray deposit sampling are Barry el al. (1978) and Dumbauld and Rafferty (1977).

The Rotorod sampler (Ted Brown Associates, 1976; and Edmonds, 1972), remains one of the simplest and reliable samplers available for collecting both chemical and some biological aerosol particles by impaction on its rotating bars. It is more commonly used to monitor seasonal airborne pollen levels. The Rotorod, consisting of a metal bar (U or H-shaped), is rotated by a 12-volt motor thus collecting particles by impaction. The U-shaped rod is close to 100 percent efficient in collecting particles 15-25 micrometers in diameter while the H-shaped rod has a lower efficiency and is designed to collect 1-5 micrometer diameter particles. This of course is dependent upon maintaining the 2400 rpm of the Rotorod motor. The rods can be assayed microscopically by use of a color tracer chemically for the active ingredient or tracer, or biologically in case a biological tracer is used (eg. Bacillus thuringiensis spores). We found the Rotorod to be an excellent sampler during a drift study of Bacillus thuringiensis in Utah (Barry et al., 1993).

CANOPY AND TARGET DEPOSITION

The Forest Service naturally has an interest in tree canopies - specifically how spray penetrates and deposits in various types of forest canopies. The scope of this interest includes what reaches and deposits on the upper canopy, what penetrates the canopy, and what impacts on the foliage upon which the insect feeds. The Forest Service and its cooperators have sponsored a broad array of studies to investigate the penetration of spray into both coniferous and deciduous canopies. A literature search will produce numerous studies (Barry, 1984). Early work on penetration of spray into a coniferous canopy showed that the small drops (less than 100 micrometers) from low volume application penetrate while those large drops (larger than 100 micrometers) are "scavenged" in the upper tree crown (Grim and Barry, 1976). Ultra low volume applications, such as is used with aerial application of Bacillus thuringiensis to control gypsy moth, have been shown to penetrate scrub oak canopies and deposit about 30 percent of the material on the forest floor (Grim et al., 1992 and Teske et al., 1994). Large volume spray applied to a foliated almond orchard with mean canopy height of 9 meters, showed a penetration of 15 percent of the spray based upon recoveries at ground level (Newton et al., 1989).

This interest was extended to impaction and deposition studies of the Western Spruce budworm where Himel and Moore (1967) reported that 93 percent of the affected larvae had not been contacted by any drops larger than 50 micrometers. This was a significant finding because 95 percent of the spray mass applied was in drops larger than 50 micrometers. Work reported by others in the

Forest Service using different tracer techniques reported that the majority of drops found on larvae and foliage was less than 50 micrometers (Roberts et al., 1971; Barry et al., 1974; Barry et al., 1977;, Barry and Ekblad, 1978; Barry et al., 1981;, Barry, 1984a, and Barry, 1984b).

We have learned the techniques of conducting canopy penetration and foliage deposition studies and have gained some insight into the behavior of high, low, and ultra low volume applications into tree canopies. The data support use of ultra low volume sprays that deliver drops in the 20-100 micrometer size range to the target.

ENVIRONMENTAL IMPACT

An active program is maintained by the Forest Service National Center for Forest Health Management (USDA Forest Service, 1995) to study impact on non-target species from pest management actions and related natural ecosystem functions. Even though Bacillus thuringiensis occurs naturally in the environment, there is concern about additional application of Bacillus thuringiensis that might impact on non-target species. The Forest Service and Canadian Forest Service maintain an extensive non-target insecticide impact database. Some opponents would ban its use in forestry leaving us few options for direct control of exotic lepidopteran insects.

The FSCBG model provides an ideal connection for scientists who are working on the environmental fate of pesticides. FSCBG can predict distribution of the pesticide on foliage, ground, and other surfaces. There are other models that can predict the movement and fate of the deposited materials. This was the subject of a symposium convened by Barry and Riley (1993). Seven papers were published on the proceedings of this symposium by the Society of Environmental Toxicology and Chemistry.

SIMULATION MODELS FOR ENVIRONMENTAL PROBLEMS

The Canadian Environmental Assessment Research Council sponsored an excellent overview paper (Broissia 1986) on environmental models for environmental impact assessment. Undoubtedly this paper has been updated or superseded by others, however, this edition is excellent in reviewing the various type of models such as the Gaussian (Pasquill-Gifford) upon which the dispersion/dosage part of FSCBG is based and Lagrangian upon which FSCBG aircraft wake dispersion is based. The paper describes the various models and their limitation and capabilities for environmental problems. This publication is recommended to those who would like to review environmental modeling. Bob Mickle who will speak at this morning's session is a scientific user of such models and a recommended consultant.

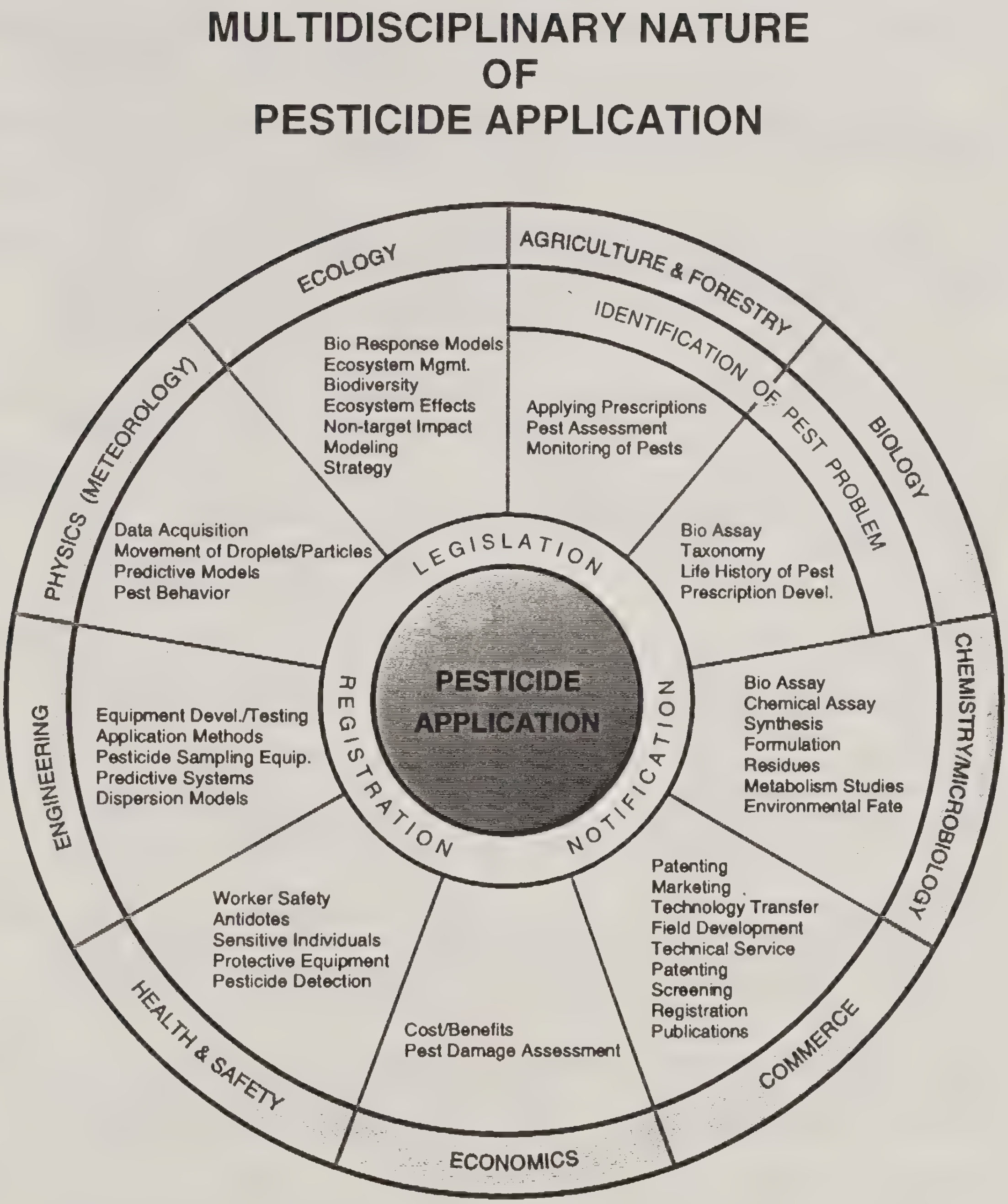
DECISION SUPPORT SYSTEMS

Decision support systems (DSS) are being developed for the resource manager to assist them in making sound decisions within a world encumbered with information and options. New Zealand (NZ) (Mason et al., 1991 and Mason, 1992) has developed a DSS for herbicide selection and alternative control strategies. At the initiation of the NZ Aerial Spray Modelling Research Group, a group made up of members from NZ Forest Research Institute, NZ forest companies, DowElanco, Monsanto, and the NZ agricultural aviation industry, New Zealand will be coordinating the development of a DSS for aerial application of herbicides (Richardson and Ray, 1994 and USDA Forest Service, 1994). The USDA Forest Service will be a cooperator with the Forest Research Institute and the NZ Spray Modelling Research Group in development of the DSS. This DSS will use FSCBG as its foundation. As pointed out by Richardson (1994), the DSS will be a practical tool based upon solid assumptions that field people will use to provide information on potential environmental impact of herbicides, biological impact on target (and non-target) plants, and cost of application. In essence we will be extending the power of the FSCBG model to predict biological effects, both wanted and unwanted. Graphic outputs, designed for ease of understanding and application, will, as an example, show biological response as a function of dose deposition/exposure and width of buffer strips needed to protect sensitive areas. The practicality of the DSS will virtually ensure its use when environmental impact and costs are at issue, which, of course, is nearly always. A detailed study plan on development of DSS is being prepared jointly by NZ Forest Research Institute and the USDA Forest Service. The DSS can serve as a model for other DSS systems using FSCBG as the base model.

SUMMARY

This paper has reviewed some of the highlights of the USDA Forest Service's pesticide environmental fate and application development program. Aerial application technology developed by the US Department of Agriculture, Department of Defense, and others positions us to apply insecticides in a safe, efficacious, economical and environmentally acceptable manner. FSCBG is a powerful tool that contains and allows use of what is generally known about application technology. Technically, I believe we have mastered pesticide application. Transfer of this technology and training of field personnel in application, however, fall short of the mark. Today the public continues its demand for protection from harmful and damaging insects, but they have little tolerance for environmental contamination and impact. Thus we must apply all existing knowledge to the challenges of insecticide application. The Forest Service is pleased to share its technology noting that technology transfer and training remains the responsibility of the user organization. There is

much more to the story but hopefully in this short time I have covered some areas of interest and have possibly stimulated a few ideas.



Modified from Matthews, G.A. 1979. Pesticide Application Methods. London:Longman, pp 334.

Figure 1 - Multidisciplinary nature of pesticide application.

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